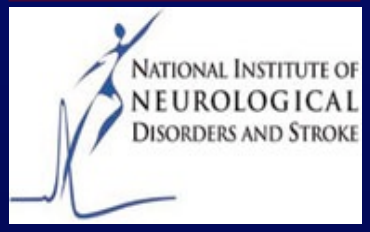
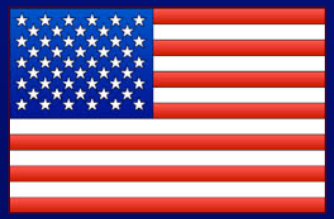
REAL-TIME FMRI:

setup, image monitoring, statistics, and feedback

Ziad S Saad, PhD

SSCC / NIMH & NINDS / NIH / DHHS / USA / EARTH





Why bother?

- Image quality control
  - Spikes, distortion, ghosting, noise, …
  - Amount of motion

Cox, RW et al. 95,
Cohen, MS et al. 98,
Frank, J. et al 99,
Voyvodic, J. 99

- Functional localization
  - Localizer prior to main FMRI experiment for BCI or high-res imaging
  - Pre operative scanning
  - As Q/A in clinical settings or difficult / rare subject population
  - 'scan to criteria'

Weiskopf, N. et al 04

Yang, S. et al 08

- Teaching

Weiskopf, N et al. 2007

- Feedback and Biofeedback
  - Reduce motion
  - Alter/interfere brain function
  - Control of task/ stimulus computer
  - Classification/BCI
  - Signals in vegetative state

Yang, S. et al. 05

deCharms. RC. et al. 04
deCharms. RC. et al. 05

Posse S. et al. 03

LaConte SM. et al. 07
Yoo S. et al. 04

Owen AM et al 06

Z.S.S 8-09

Outline

- This talk will focus on AFNI's interface for real-time FMRI
  - A brief intro to the interactive interface
  - Demo I: simple image monitoring
  - Demo II: Demo I + GLM
  - Demo III: Feedback
  - Demo IV: Classification ?
  - AFNI & SUMA Automation

Image Quality Control

- Image quality control
  - Spikes, distortion, ghosting, noise, …
  - Amount of motion

Cox, RW et al. 95,
Cohen, MS et al. 98,
Frank, J. et al 99,
Voyvodic, J. 99
Weiskopf, N et al. 2007

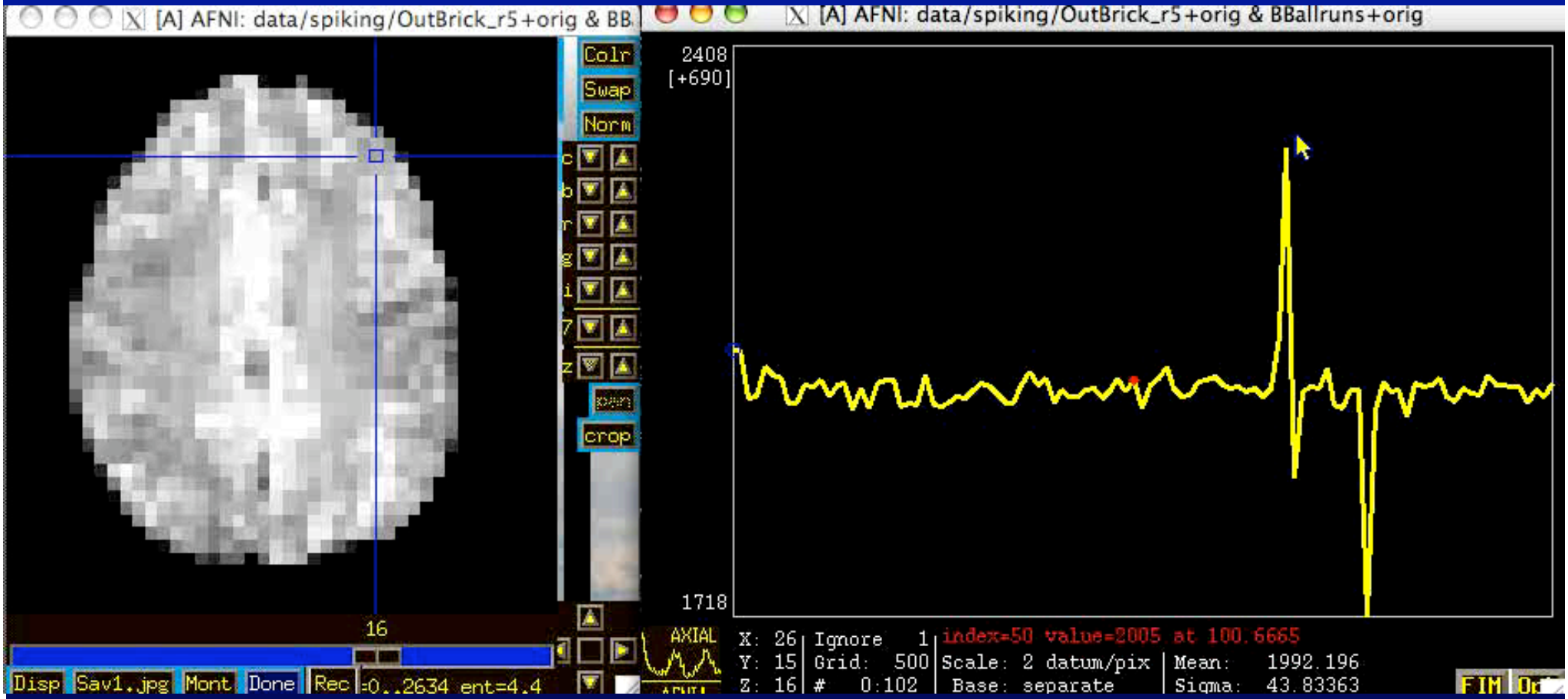


Image Quality Control

- Image quality control
  - Spikes, distortion, ghosting, noise, …
  - Amount of motion

Cox, RW et al. 95,
Cohen, MS et al. 98,
Frank, J. et al 99,
Voyvodic, J. 99
Weiskopf, N et al. 2007

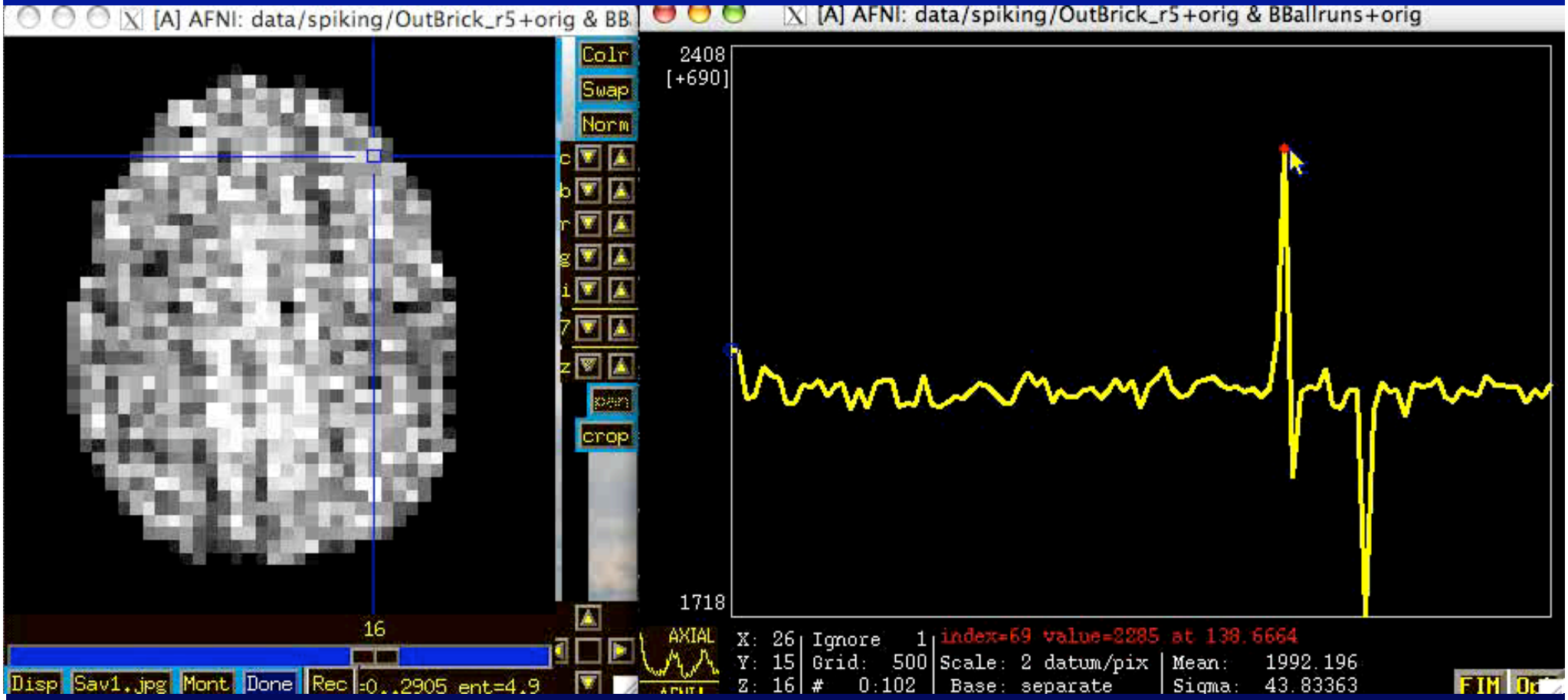
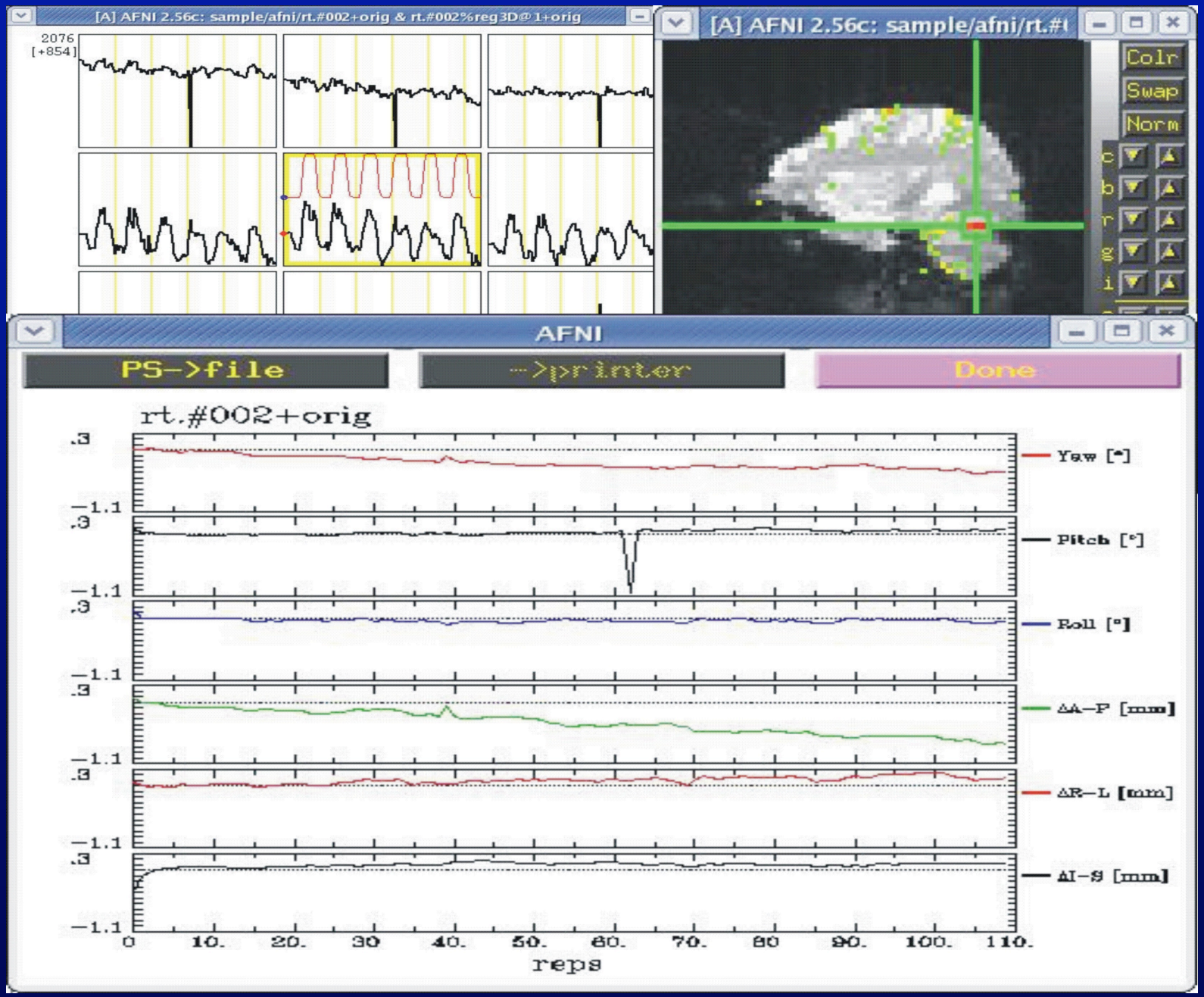


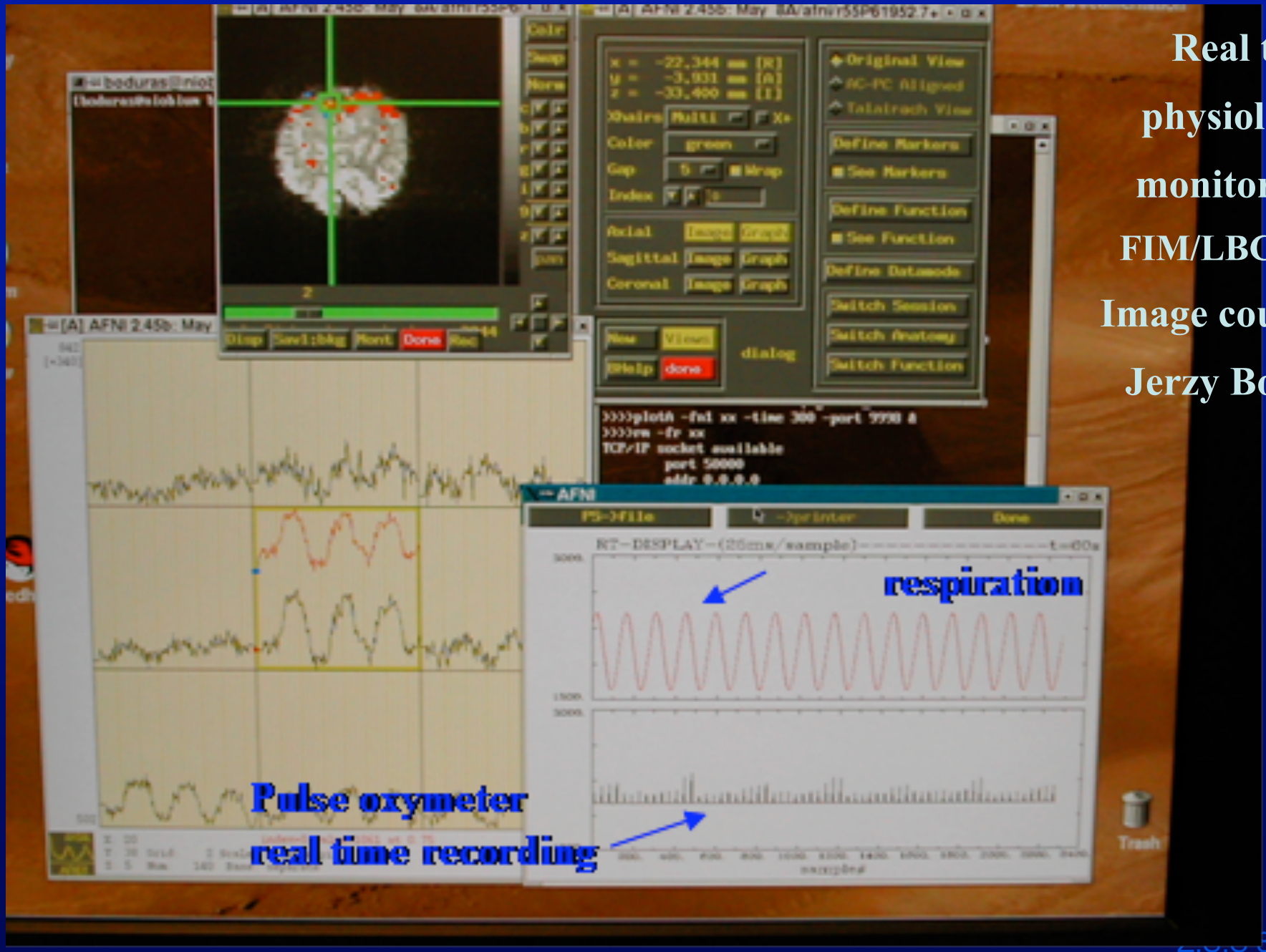
Image Quality Control



Real-time Estimation of Functional Activation

Real-time Estimation of subject movement

Image Quality Control



Real time physiological monitoring at FIM/LBC/NIMH

Image courtesy of Jerzy Bodurka

Image Quality Control

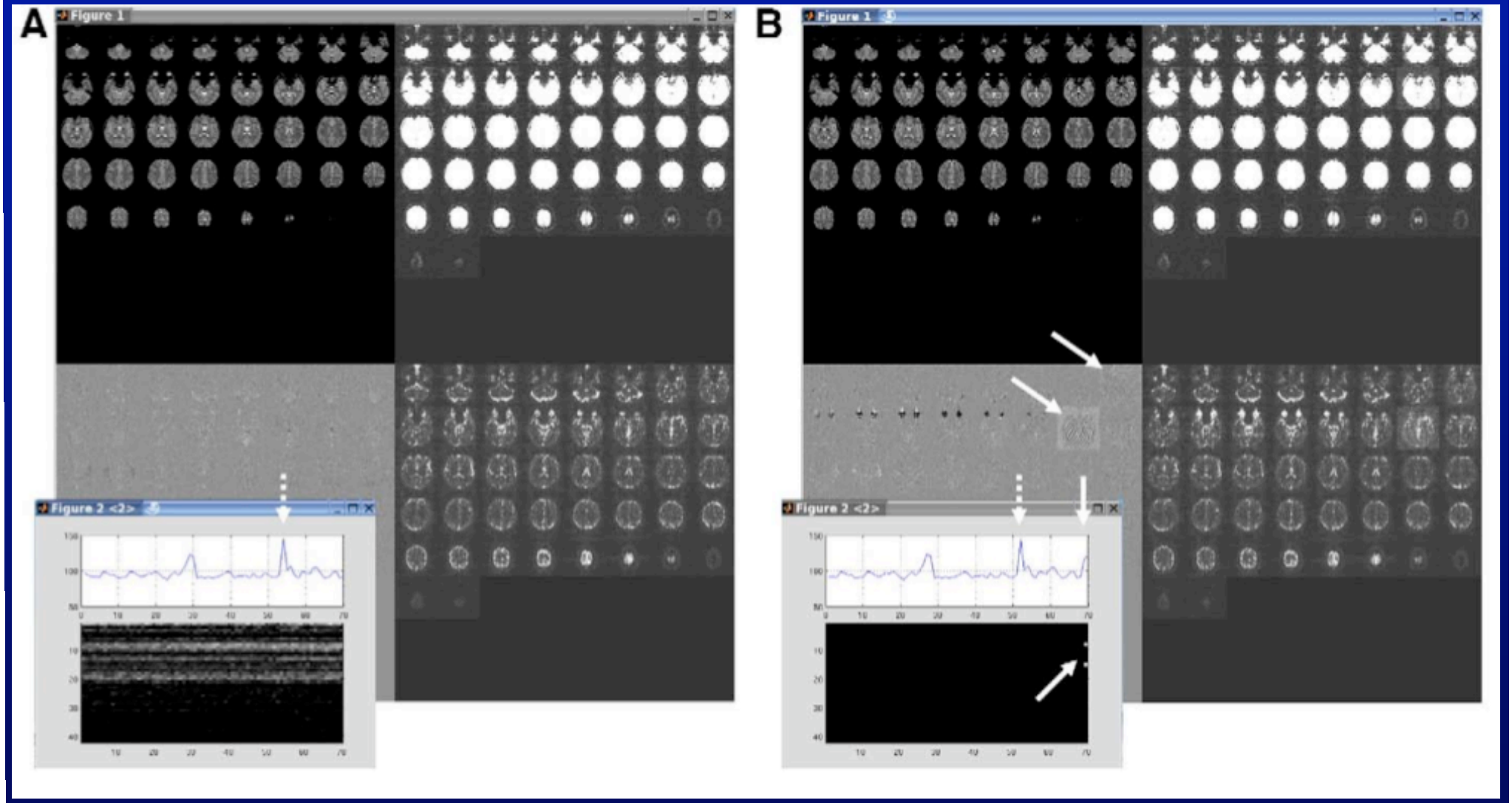


Fig. 1. From Weiskopf, N. et al. MRI 07

Reduce Motion with Feedback

- Feedback and Biofeedback
  - Reduce motion

Yang, S. et al. 08

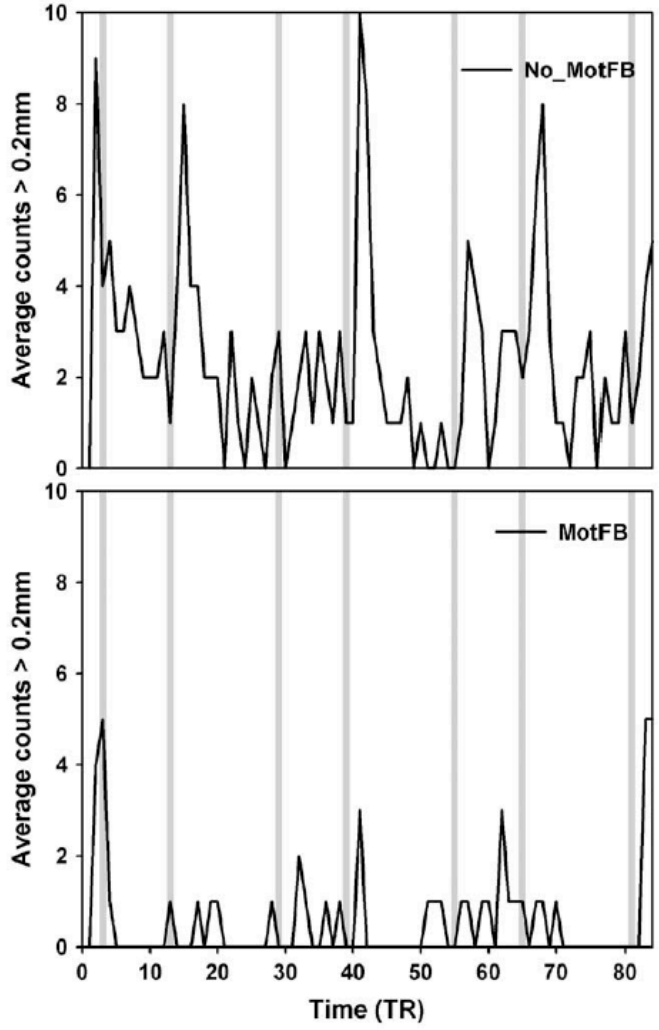


Fig.6 from Yang, S. et al. Neuroimage 05

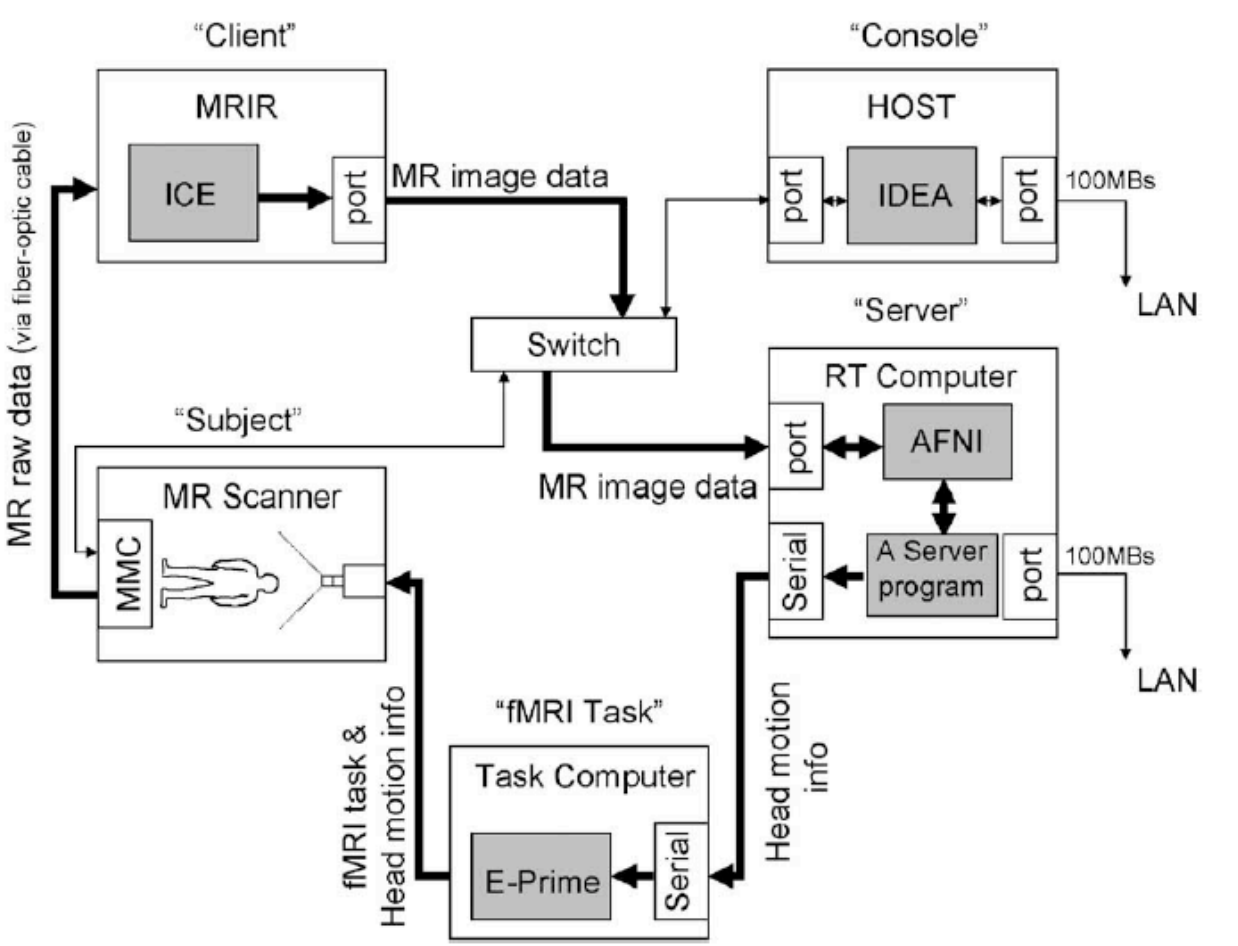


Fig. 2. Configuration of the real-time analysis system and data flow schematic.

Fig.2 from Yang, S. et al. Neuroimage 05

Activation in Vegetative State

Patient and control responses to audio instructions

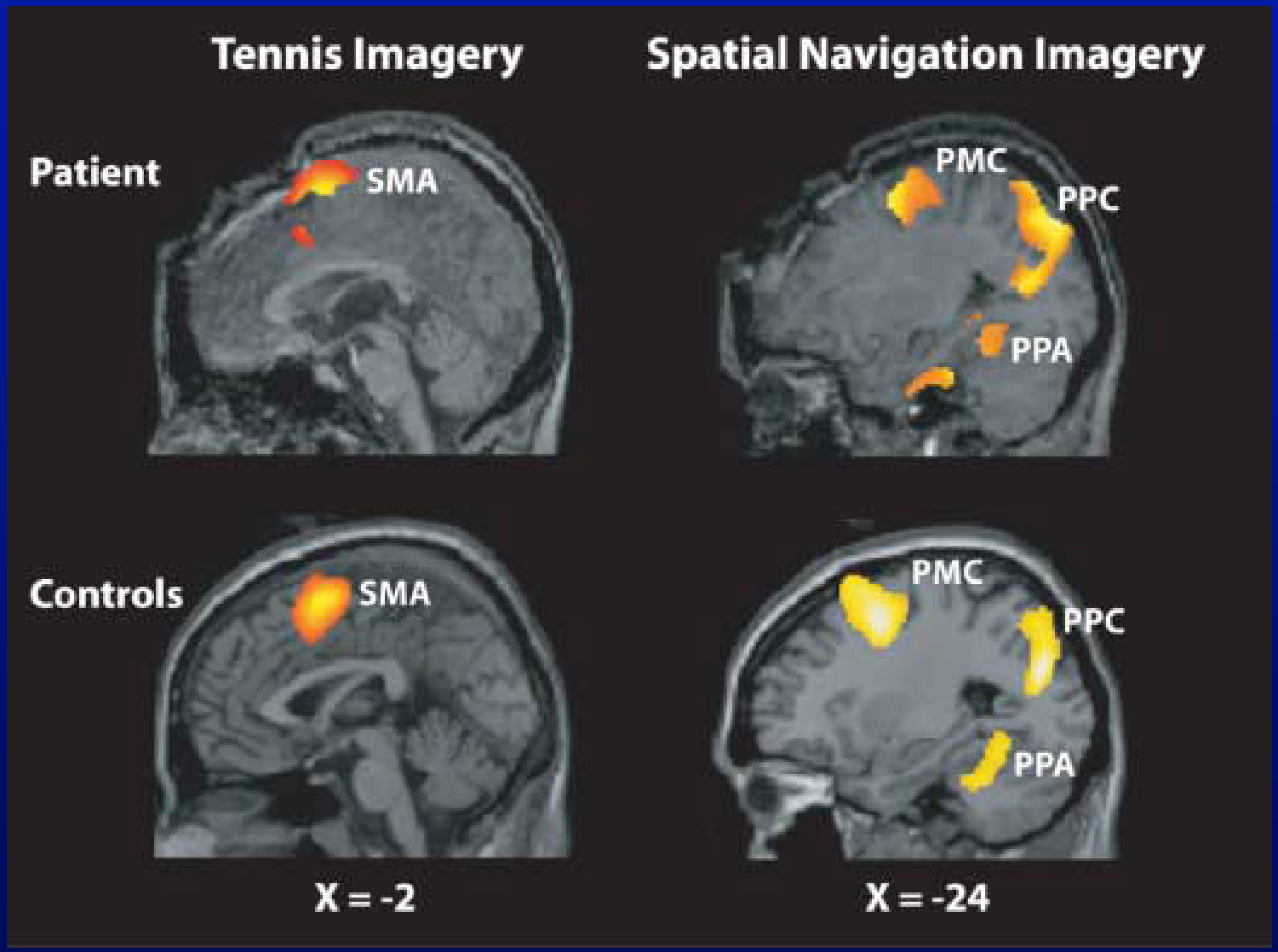
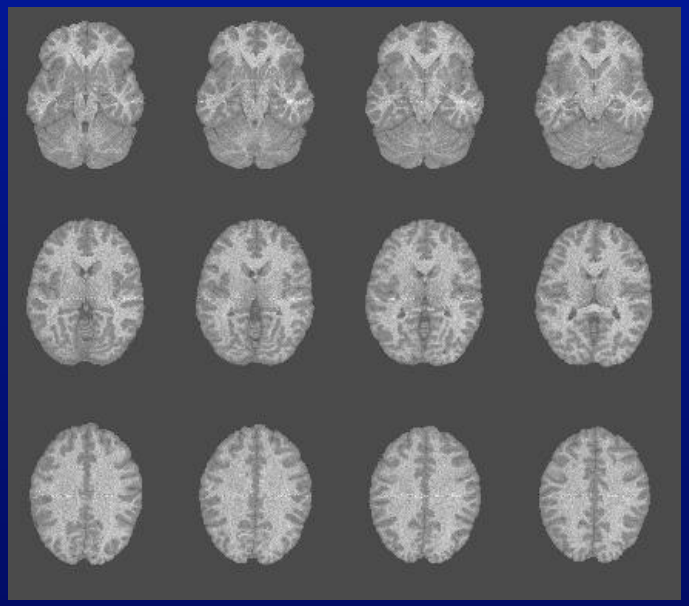
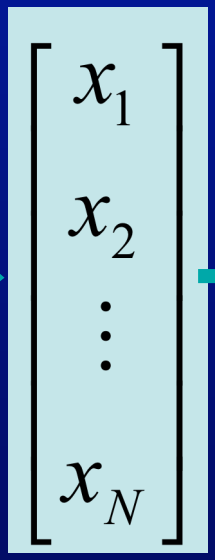


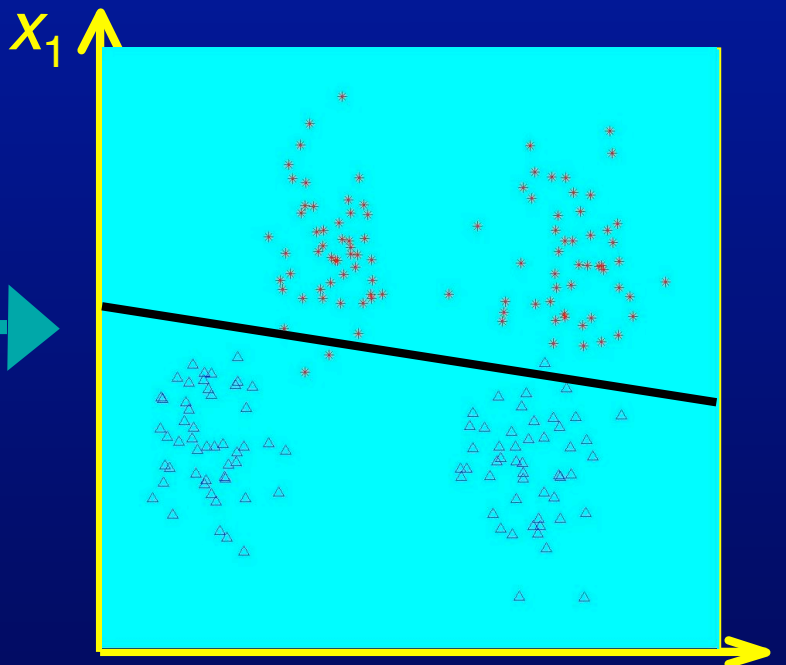
Fig.1 from Owen AM et al, Science 06

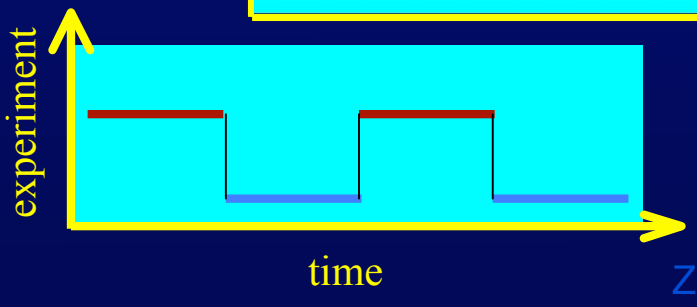
Classification

- Classification maps high dimensional pattern into a set of classes
  - This allows a complex brain activation pattern to be identified with a set of classes or brain states.
  - Useful in to providing intuitive feedback from activation of multiple areas
  - Useful for inferring brain state
    - Strother, Cox Savoy, Haxby, Beauchamp, Kendrick Kay's









Brain Computer Interface

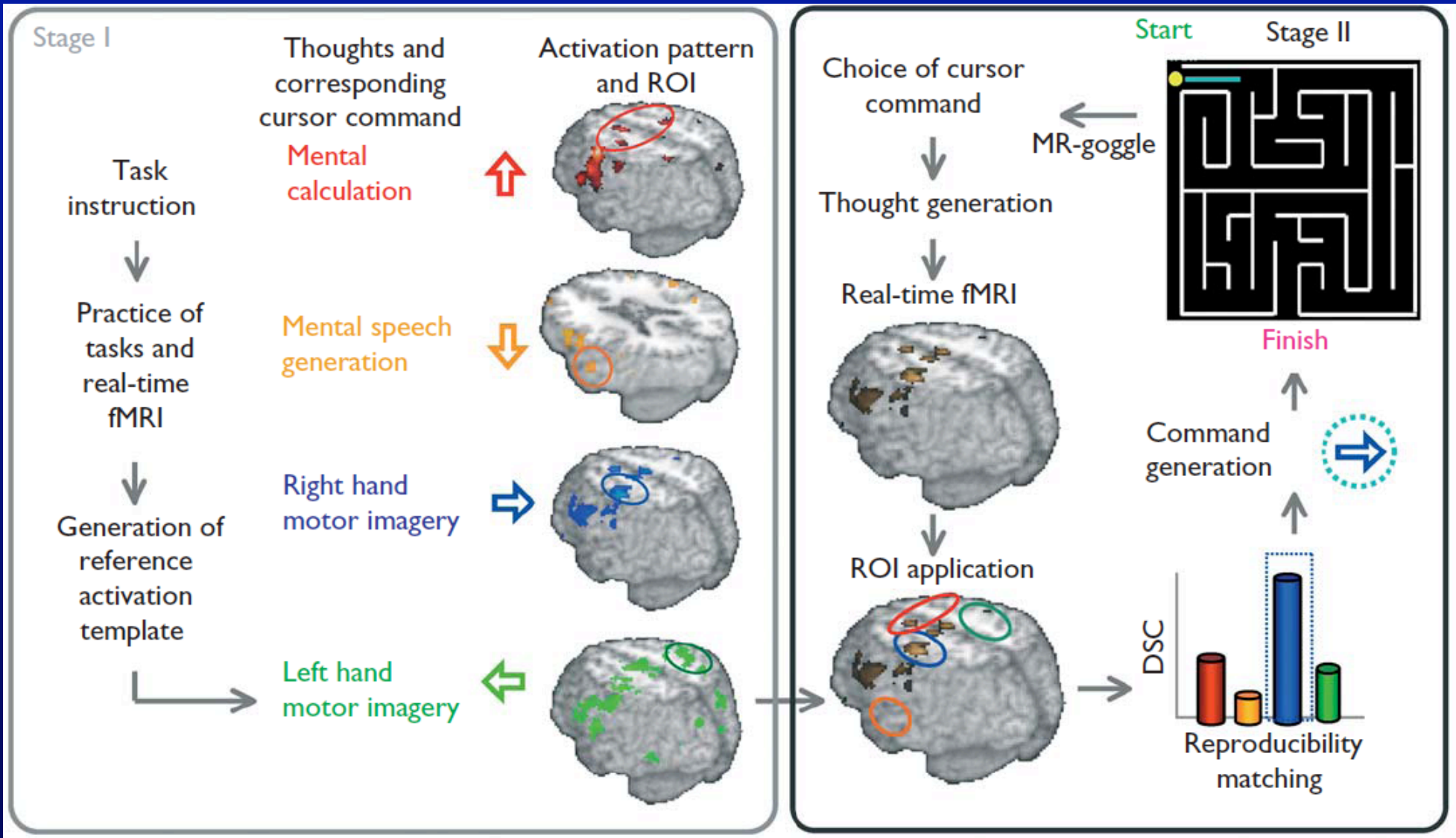


Fig.1 Yoo S. et al. Neuroreport 04

Why bother?

- Reviews:
  - Weiskopf N et al.: Real-time functional magnetic resonance imaging: methods and applications. *Magnetic Resonance Imaging 25 (2007)*
  - Yang S et al.: Real-Time Functional Magnetic Resonance Imaging and its Applications. in *Brain Mapping Research Developments, Bakker LN ed., Nova Publishing, New Jersey (2008)*
  - deCharms RC: Applications of real-time fMRI. *Nature Reviews Neuroscience **9** (2008)*
  - deCharms RC: Reading and controlling human brain activation using real-time functional magnetic resonance imaging. *Trends in Cognitive Sciences **11** (2007)*

The players

Image Monitor

Scanner

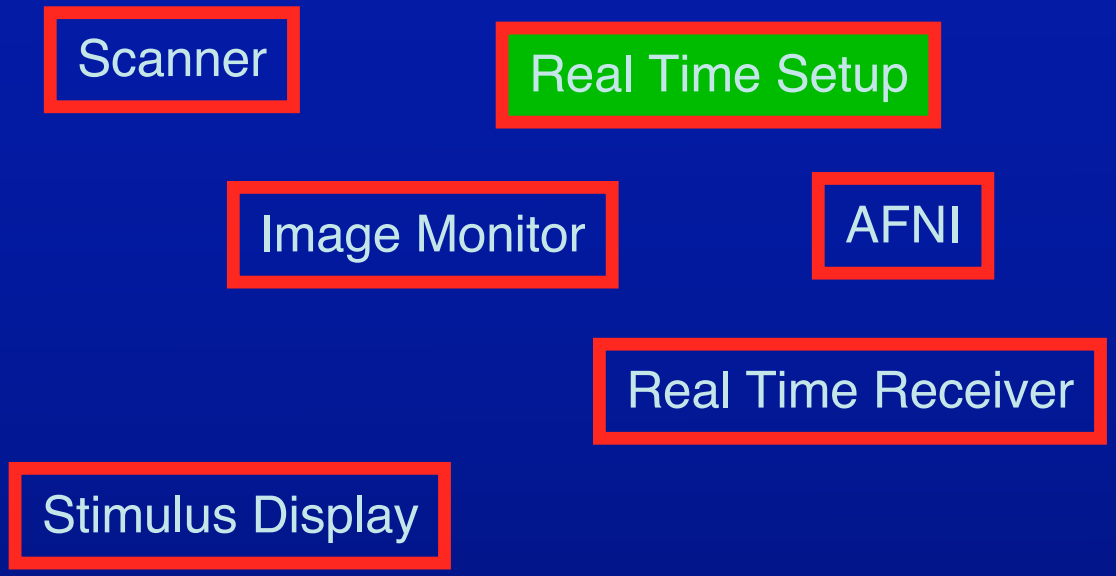
AFNI

Real Time Setup

Stimulus Display

Real Time Receiver

The players



- Real Time Setup
  - A user-supplied set of commands that tell AFNI what to do with incoming data
  - Can be done from shell commands or from within C code
  - Communicates with AFNI through TCP/IP socket
  - Sets up ROIs for AFNI*. (need to show example of ROI selection. Either single subject-based or atlas based).

Real time setup example

- A module from the demo
- @fast_roi

```
@fast_roi    -region CA_N27_ML::Hip \
             -region CA_N27_ML::Amygda \
             -base TT_N27_r2+tlrc. \
             -anat doe_SurfVol_AInd_Exp+orig. \
             -roi_grid blur_vr_run1_motor_AFB003+orig. \
             -prefix hip_amy -time
```

- Freesurfer based selection

ROI selection options

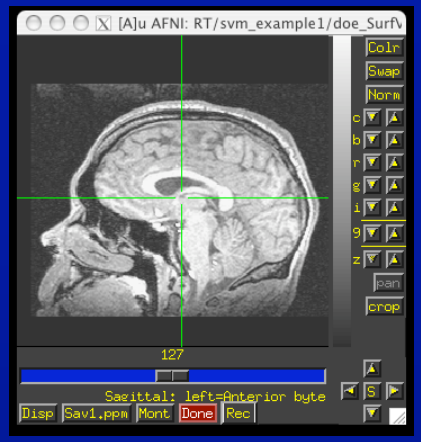
- Standard atlases
  - TT_Daemon :
    - Created by tracing Talairach and Tournoux brain illustrations.
    - Contibuted by Jack Lancaster and Peter Fox of RIC UTHSCSA
  - CA_N27_MPM, CA_N27_ML, CA_N27_PM :
    - Anatomy Toolbox's atlases, some created from cytoarchitectonic
    - studies of 10 human post-mortem brains
    - contributed by Simon Eickhoff, Katrin Amunts and Karl Zilles of IME, Julich,
- FreeSurfer, subject-based
- Functional localizer
- Etc.

Standard-space atlas_ROI selection

```
@fast_roi -region CA_N27_ML::Hip \
          -region CA_N27_ML::Amygda \
          -base TT_N27_r2+tlrc. \
          -anat doe_SurfVol_Alnd_Exp+orig. \
          -roi_grid blur_vr_run1_motor_AFB003+orig. \
          -prefix hip_amy -time
```

- less than 1min including skull stripping and transform to TLRC
- A couple of seconds for generating more ROIs

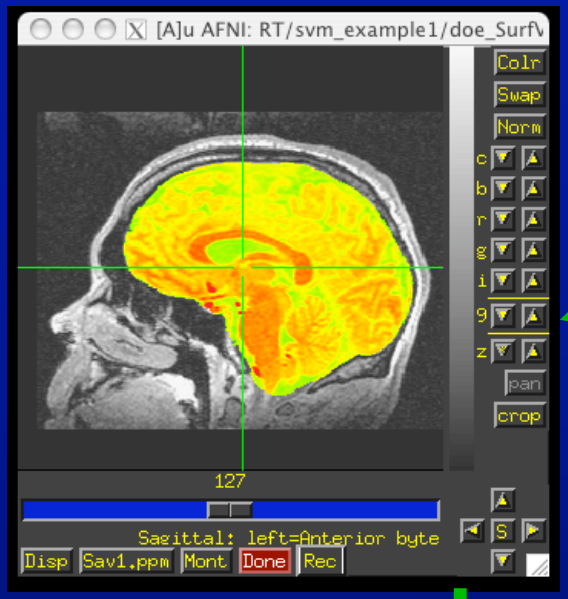
Atlas-based ROIs



1- Strip skull

2- Find xform to atlas space

(about 40 secs, 2.5GhZ cpu)



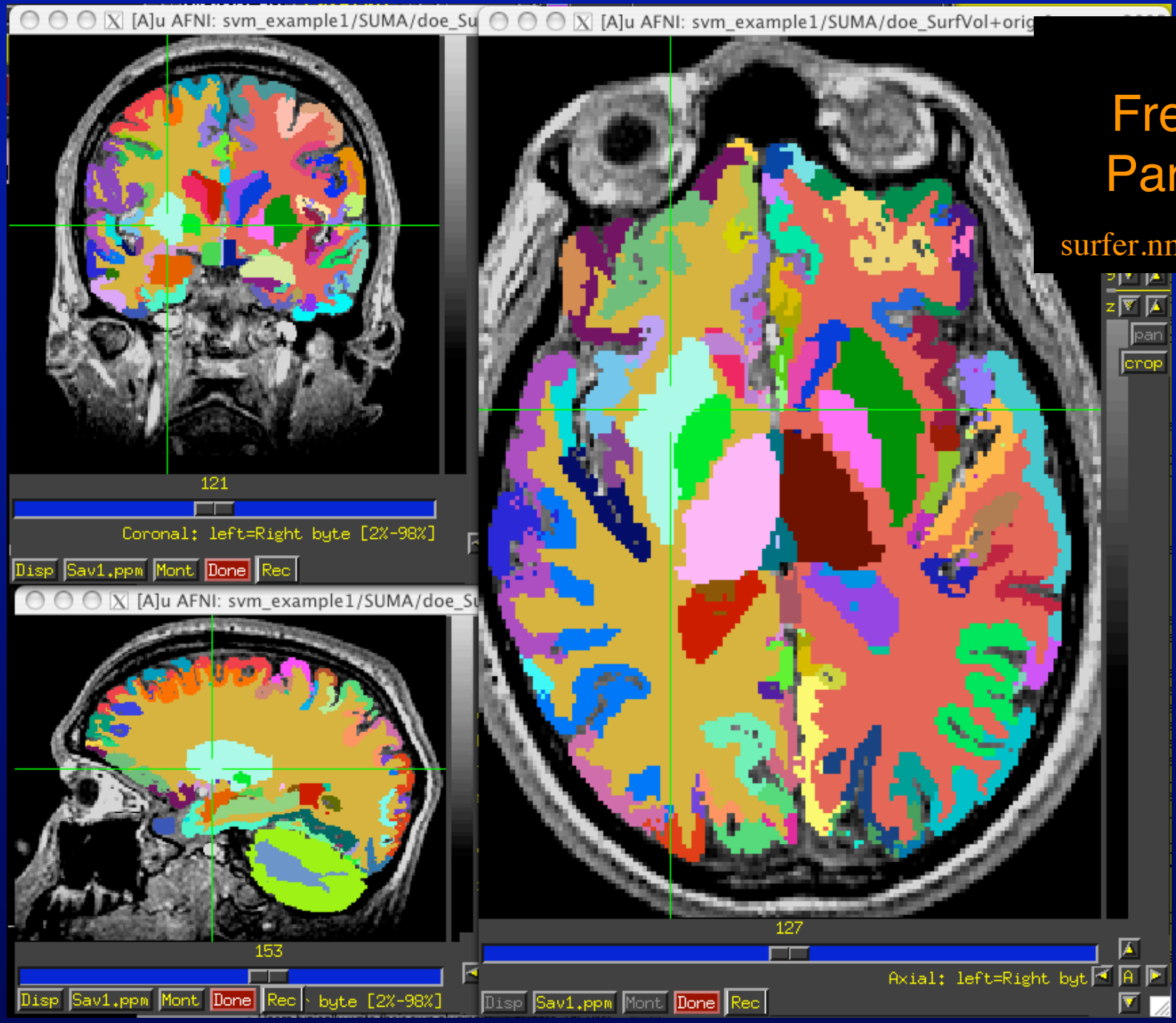
3- Identify ROIs

4- Xform ROIs to native space

(about 2 seconds)

Z.S.S 8-09

Subject-based Anatomical ROIs

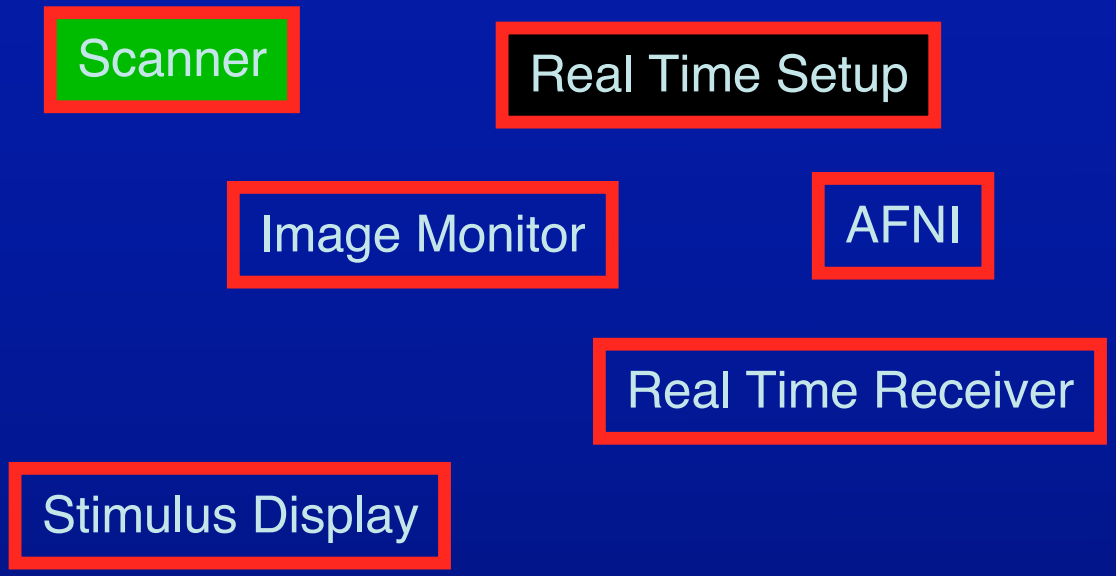


From FreeSurfer's Parcellations

surfer.nmr.mgh.harvard.edu

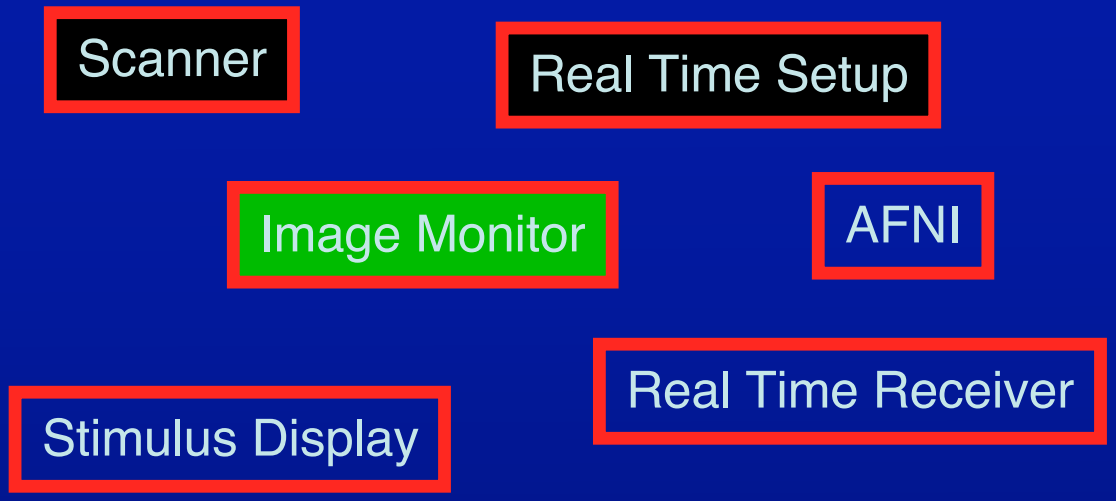
Z.S.S 8-09

The players



- Scanner
  - A user-supplied machine to acquire and reconstruct images in real time

The players

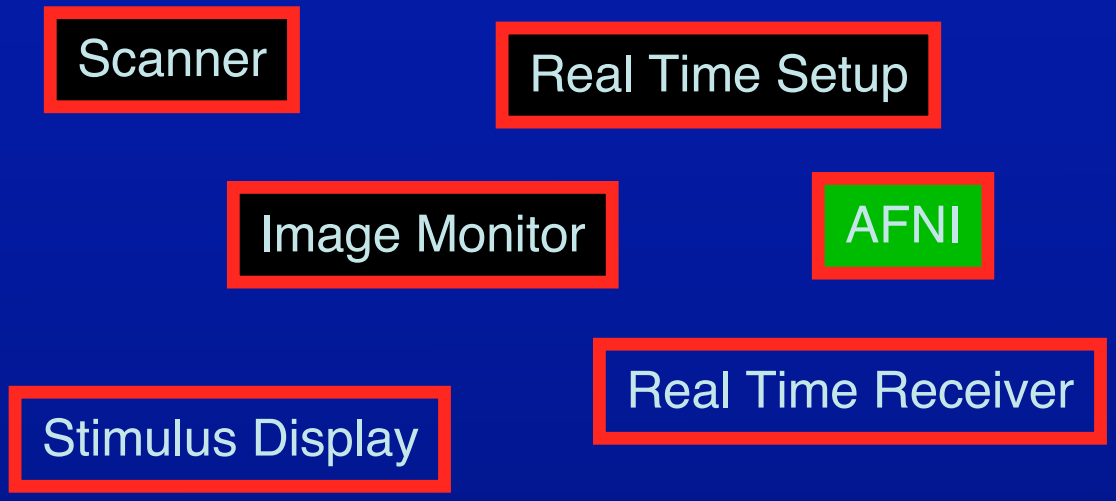


- Image Monitor
  - An AFNI- or user- supplied program to wait for scanner reconstructed images
    - AFNI-supplied programs monitor files only:
      - Imon (Monitors GE's old dreaded I files)
      - Dimon (Monitors GE's DICOM images)
      - RTfeedme (Breaks up and AFNI readable dataset and sends it to AFNI)
    - User-supplied programs usually interface with scanner software directly
      - SIEMENS TRIO(?) via functors (S. LaConte BCM, E. Stein NIDA)
    - Usually only program that runs on scanner computer
      - But even that is not necessary
  - Image Monitor sends images or volumes to AFNI over TCP/IP socket as they become available

Image Monitor example

- A module from the demo
- If there is time, add flowchart to point to small but pesky problems that they should watch for.

The players

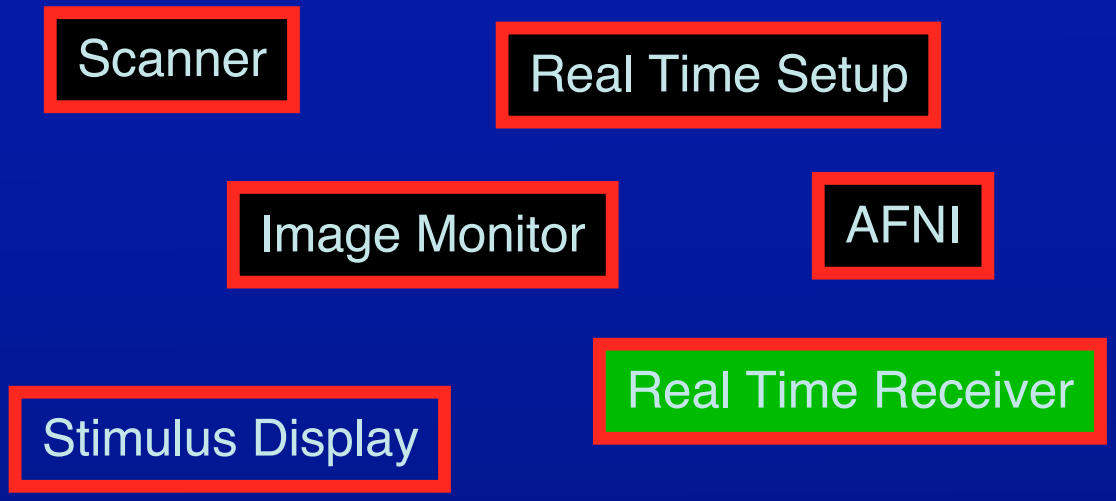


- AFNI
  - AFNI-GUI application expects incoming images/volumes and processes them per the setup instructions
    - Assemble images/volumes into time series
    - Perform image registration
    - Perform (multi*) linear regression
    - Send results to Real Time Receiver through TCP/IP socket
      - Raw, volume registered, or residual volume*
    - Send raw or processed volumes to plugin that register to receive them
      - Much faster than TCP/IP (just a data pointer is passed)
      - Users typically write their own plugins (S. LaConte 3dSVM)
      - Plugins can also communicate with Real Time Receiver
    - Send data from pre-defined ROIs to Real Time Receiver

AFNI example

- Should probably show the kinds of data to AFNI sends
- Maybe a picture of a plugin
- Maybe some code to show how plugin requests data?
- Two tables of ROI-based values as they get sent

The players



- Real Time Receiver
  - AFNI- or User- supplied application that expects incoming data from AFNI and acts on it
    - Motion parameters
    - ROI-based data, all values or just average
    - Entire volumes of raw, or preprocessed data
    - Data from any RT plugin such as 3dsvm
  - Process incoming data to your liking
  - Optionally forward results to Stimulus Display either by serial connection, or TCP/IP*

Receiver example

- Example from demo

- Speak of importance of scanner independent testing platforms
- Extend hand for collaboration

"Help" sources

- Which programs are available for help
- Readme files

Strategy for Manipulating Activation

Adapted from deCharms RC. TCS 07

- Providing strategy may be critical
  - Subjects overestimate ability to control activation
  - Start by providing strategy that activates ROIs regions providing feedback
- See literature on control of various areas

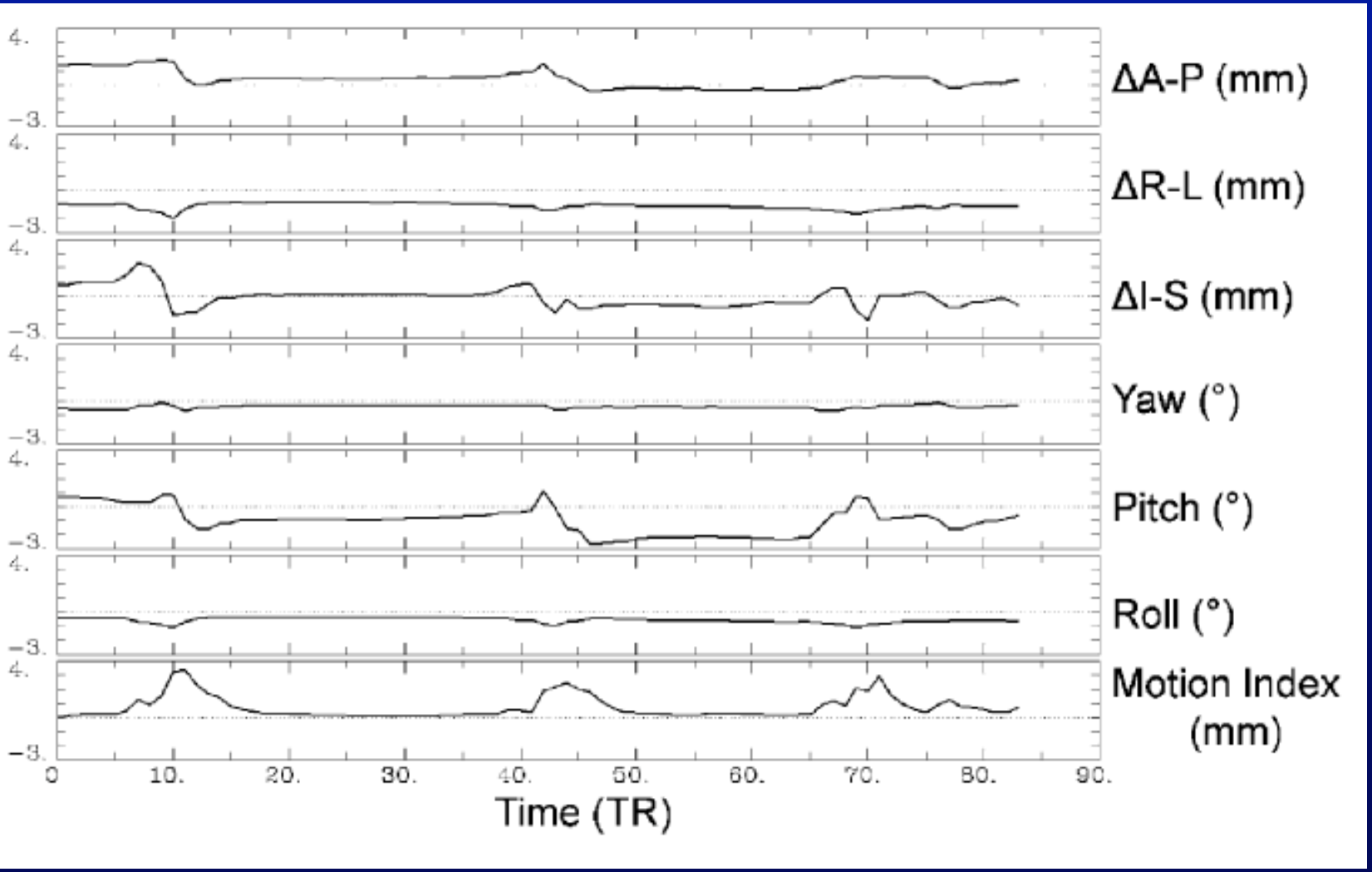
From LaConte S. – FMRI Advanced Issues ISMRM 09

  - Somatomotor cortex
    - Posse 2001, Yoo 2002, deCharms 2004, Yoo 2004
  - Parahippocampal place area
    - Weiskopf 2004
  - Amygdala
    - Posse 2003
  - Insular cortex
    - Caria 2007
  - Anterior cingulate cortex
    - Weiskopf 2003, Yoo 2004, Birbaumer 2007, deCharms 2005

Feedback Design

- If incidental to task, minimize interference

Too much information!



Feedback Design

- If incidental to task, minimize interference

Minimum Task Interference

Enough information

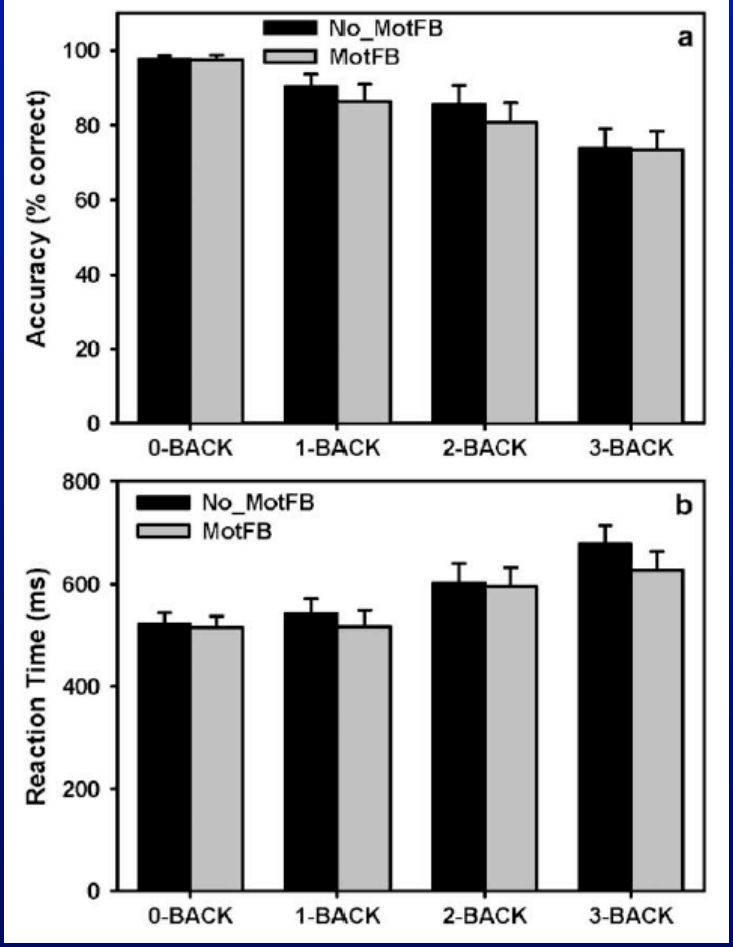


Fig.7 from Yang, S. et al. Neuroimage 05

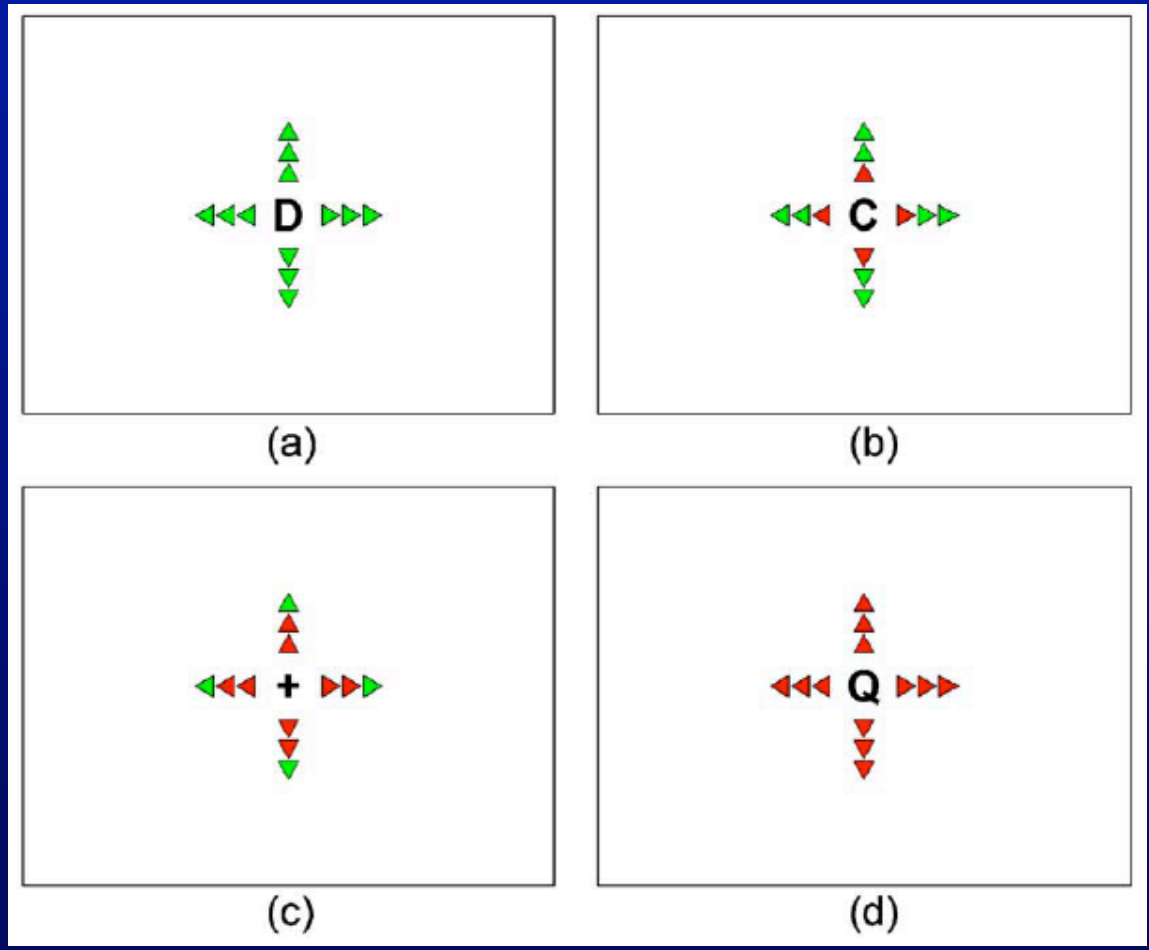


Fig.3 from Yang, S. et al. Neuroimage 05

Z.S.S 8-09

Feedback Design

- Make it appealing to subject
  - Turns out few get excited about graphs!
  - Fire on the beach = much more exciting

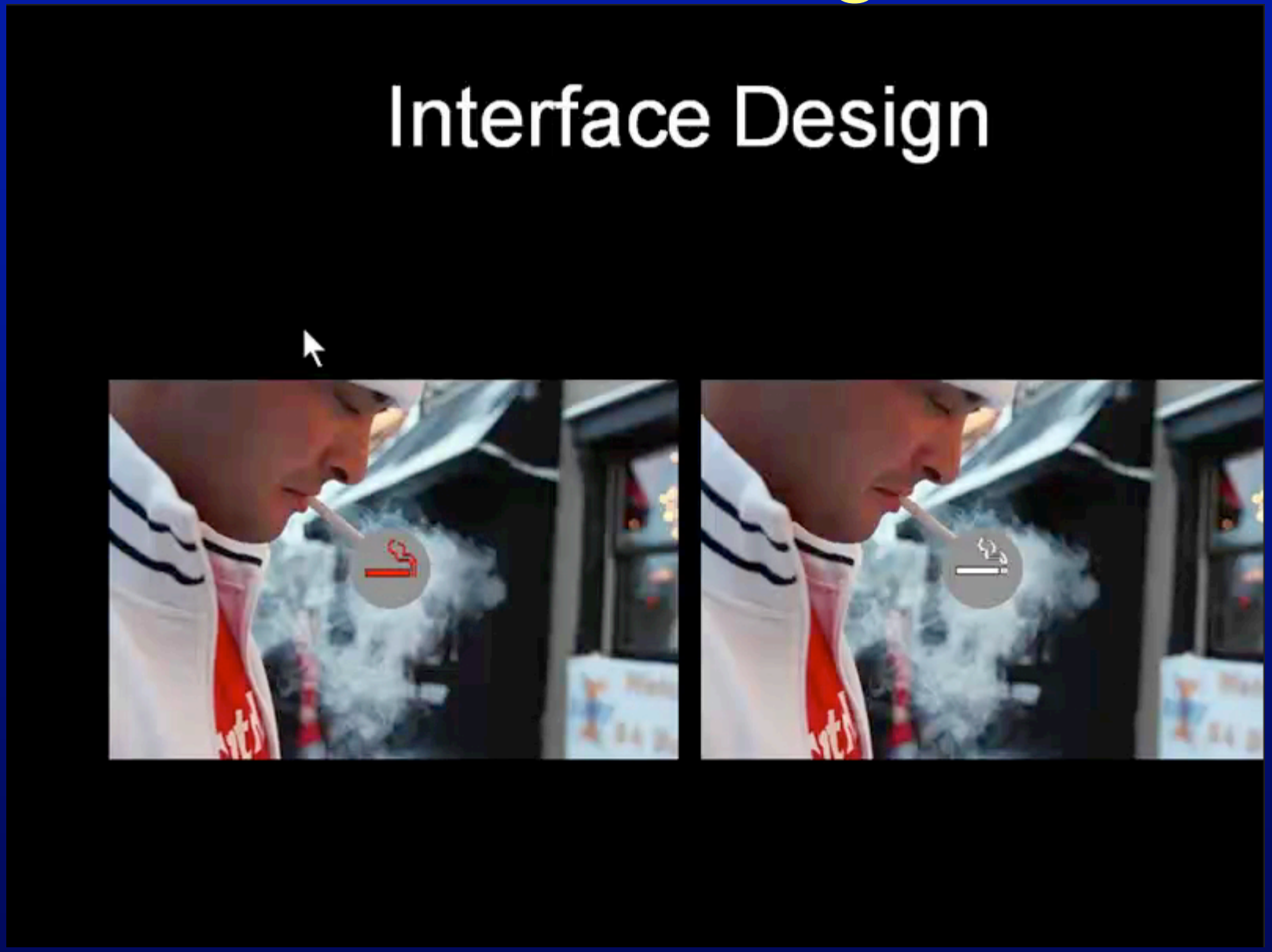
Figure 1d from deCharms RC. Nature 08

Feedback Design

- OMG! Asteroids!
  - Keeps subject interested
  - History trace helps subject cope with FMRI response lag

Courtesy of Zhang Y., Kurup P., Ross T. and Stein A. NIDA/NIH

Feedback Design

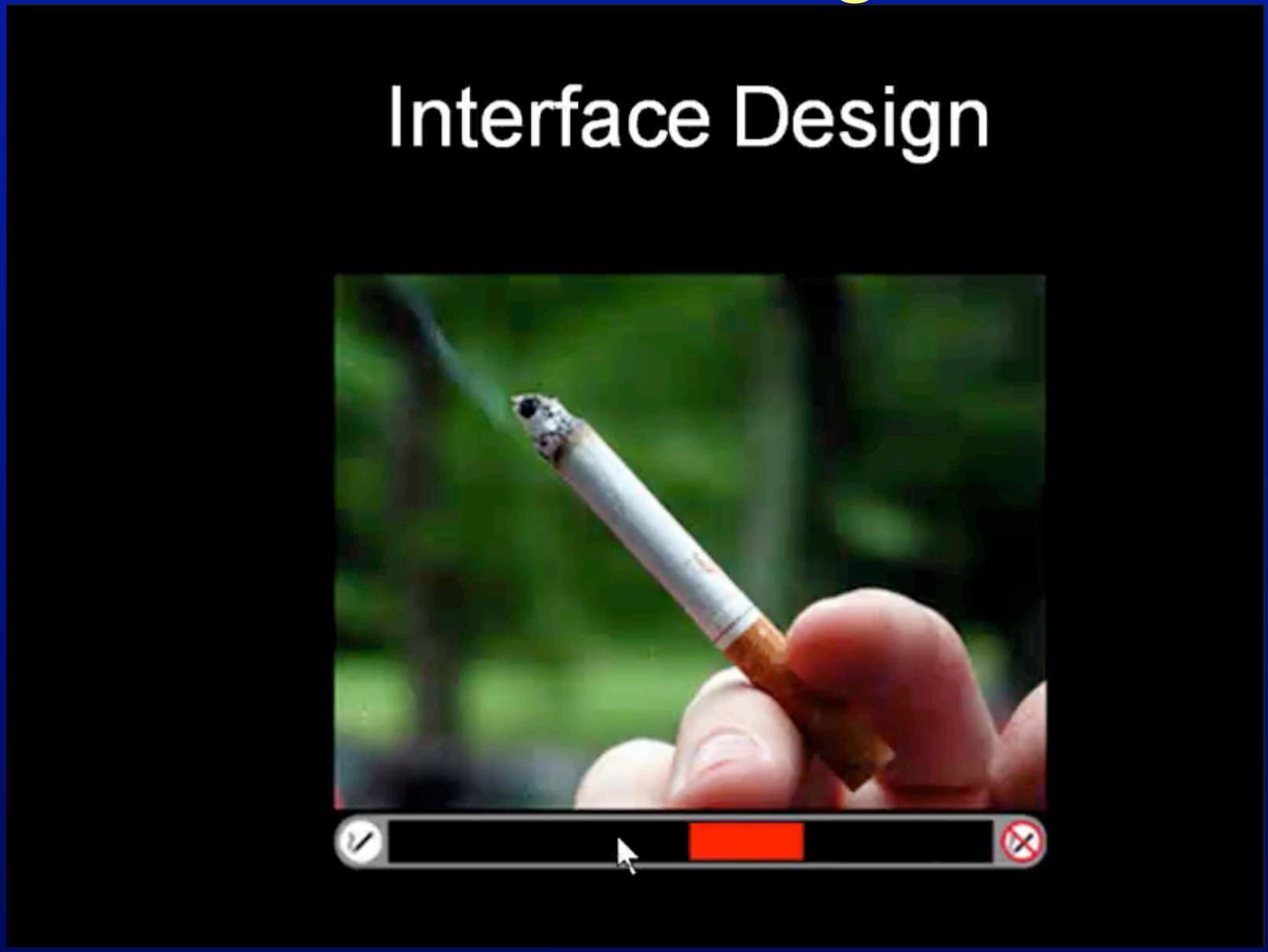


From S. LaConte ISMRM 09

Feedback Design

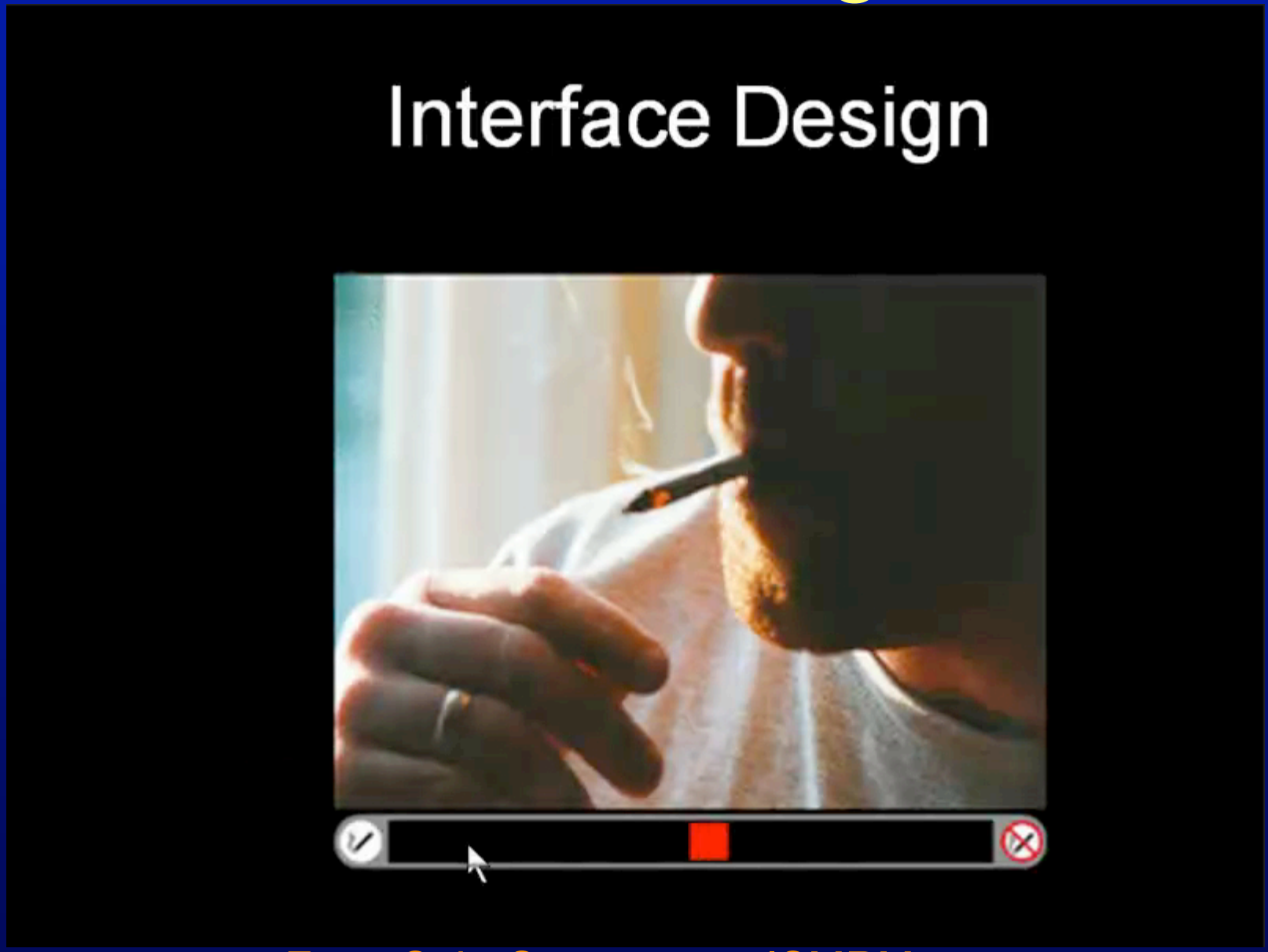
From S. LaConte ISMRM 09

Feedback Design



From S. LaConte ISMRM 09

Feedback Design



From S. LaConte ISMRM 09

What to feedback ?

- Which signal to use?
  - From original time series
  - From filtered* time series
  - From regression (Beta/T/R) analysis
- Typically from one or more ROIs
  - Anatomical Atlas based
  - Single subject anatomy based
  - Group function based
  - Single subject localizer
- Combining information from multiple ROIs
  - Encode signals in VR scene deCharms RC. 08
  - Classifiers (ROI or whole brain), if models are known LaConte SM. 07
- What about noise confounds?
  - Control for respiration/cardiac with real-time RETROICOR*
  - Include other physiological covariates in real-time*
  - Include real-time baseline modeling

Acknowledgments

Robert Cox
Rick Reynolds

Stephen LaConte
Tomas Ross

Julien Doyon